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Range-Depth Tracking of Sounds from a Single-Point Deployment by Exploiting the Deep-Water Sound Speed Minimum

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LONG-TERM GOALS

The long-term goal of this work is to develop techniques for tracking marine mammal sounds in range and depth from a single mooring or platform (e.g. glider), by exploiting the propagation effects of the deep-water sound speed channel. Most listening platforms currently use a single hydrophone to detect events, making no effort at localization. For beaked whales (which have a limited detection range of about 5-7 km), detection may be sufficient to determine whether an animal is close to potential naval operations, but for most species, one needs to assume a typical source level (or source level distribution) to translate a detection's received level into a distance, a risky assumption that generates large uncertainties in position, which in turn degrades attempts at acoustic density estimation and makes mitigation decisions problematic.

The range of a marine mammal sound from a compact platform can also be obtained by detecting the same event across multiple platforms; however, for logistic reasons it is highly desirable to investigate avenues for permitting relatively accurate localization from a single platform.

OBJECTIVES

The primary objective of the work is to estimate the range and depth of cetacean calls using short-aperture vertical arrays, by measuring the vertical arrival angles of various refracted and bottom-reflected ray paths, and the relative arrival times between them. Single-hydrophone methods are also being examined, with a particular focus on empirical relationships between the bandwidth and temporal dispersion of received signals with measured range. Two broad classes of calls are to be examined: deep-diving odontocetes such as sperm and potentially beaked whales, and shallow-diving mysticetes, with a focus on humpback whales.

The short-aperture range estimates are to be verified by comparison with satellite-tag positions (for sperm whales) or by comparison with ranges obtained via large-aperture vertical array techniques (for humpback whales).

APPROACH

The experimental approach used by this project uses data collected by moored vertical arrays in deep water, to simulate data that would be collected by autonomous platforms. At present two experimental deployments are being used. The first is a 2010 deployment of a two-element 10-m aperture vertical array on longline fishing gear off Sitka, AK. The three-day deployment occurred in the midst of several depredating sperm whales, three of which had been tagged by satellite tags just before the deployment. Location fixes from the satellite tags are used to evaluate range estimates derived from angular measurements of the vertical array, as well as range estimates derived from heuristic expressions for pulse dispersion in the sound-speed minimum channel. The basic analytic approaches used here have previously been published by Mathias *et al* 2013.

A second deployment scheduled during this project is that of a large-aperture vertical array in the same region off Sitka, AK. The sparse array actually consists of several subarrays, including two eight-element arrays (21 m aperture) deployed at 90 and 275 m depths (the latter being the sound speed minimum), and three two-element arrays of 10 m aperture deployed at 238, 640, and 823 m depth. The motivation behind these multiple deployments is that multiple techniques can be used to estimate humpback whale call position, and thus cross-validate methods that use a relatively short-aperture array.

All deployments in this project have been conducted in collaboration with Jan Straley Sitka Sound Science Center, along with Stephen Rhoades at the Alaska Longline Fishermen's association.

WORK COMPLETED

This award was issued on June 2014. On 2014 September 23 the large-aperture vertical array was successfully deployed off Sitka at 56.61 N, -135.93 W. Figure 1 shows a photo of some 21 m array cable lying on the hatch of the F/V Magia, and Figure 2 shows a schematic of the deployment. The system is scheduled to be recovered in mid-October 2014.

RESULTS

A preliminary review of the 2010 has already located humpback whale calls. Figure 3 shows nine calls detected within a minute of each other on August 6 (04:55:41). What may not be immediately obvious is that two whales are making these calls. Figure 4 shows the elevation angles estimated from the 10 m array for the first three "fuzzy" calls (left column) and for the 300 Hz call visible at 22 sec in Fig. 3 (right column in Fig. 4). Both standard cross-correlation and adaptive beamforming techniques ("minimum-variance", or MV) are shown. A negative elevation angle is arriving from the surface, and a positive angle is arriving from the ocean floor. One sees that the first three calls in Fig. 3 are arriving between 16-17 ° below the horizontal, and thus are bottom reflections from the ocean floor. Bottom reflections are expected to be the primary means for detecting baleen whale calls in Pacific deep waters. The rather diffuse and incoherent structure of these calls can be explained by the fact that bottom-reflections tend to scatter and disrupt signal structure.

By contrast, the calls between 250 and 350 Hz are arriving from a roughly 45° angle above the horizontal, so must be arriving from a different animal. Figure 5 shows the corresponding ray trace diagram for the two calls: the red ray showing the first three calls, and the blue line showing the last call. If humpback whales generally produce these calls at depths of 50 m or less, then the bottom-reflected calls are likely 5.5 km away, with ambiguities at 12.5 and 19 km range. The lower-frequency calls must be much closer: less than 4 km range. The ambiguities may be resolvable by processing additional calls over time, by noting the degradation in coherent structure of the signal through multiple bounces, or exploiting additional multipath arrivals that are visible in the close-range call in Fig. 3. The need to identify reliable techniques to resolve ambiguities in range from single-point ray tracing remains the major research focus, and was a primary motivation behind the Sept. 2014 deployment.

IMPACT/APPLICATIONS

Most algorithms developed can be applied to one of several existing marine mammal DCL platforms. Some algorithms will require that the DCL have two hydrophones with a spatial aperture.

REFERENCES

Mathias, D., Thode, A. M., Straley, J., and Andrews, R. D. (**2013**). "Acoustic tracking of sperm whales in the Gulf of Alaska using a two-element vertical array and tags," J. Acoust. Soc. Am. **134**, 2446-2461.

Figure 1: One eight-element array being prepared for deployment.

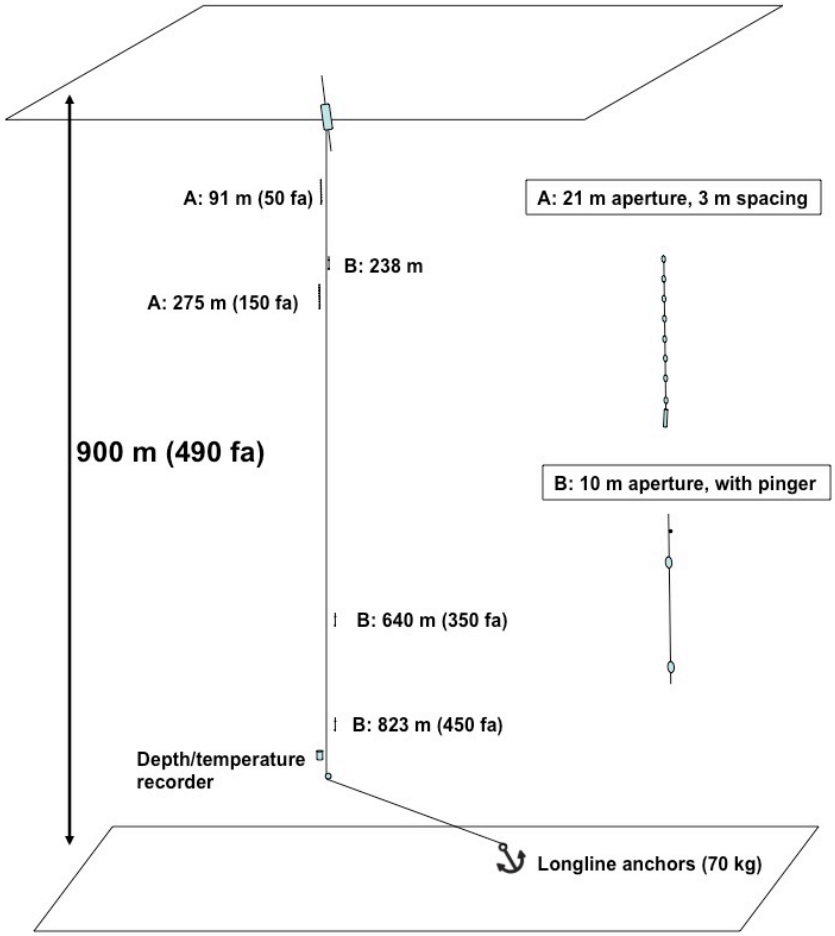

Figure 2: Diagram of Sept. 2014 deployment. The array deployment consists of two 'A' and three 'B' subarrays; the former being eight-element cabled hydrophone arrays, the latter being two autonomous recorders separated by 10 m.

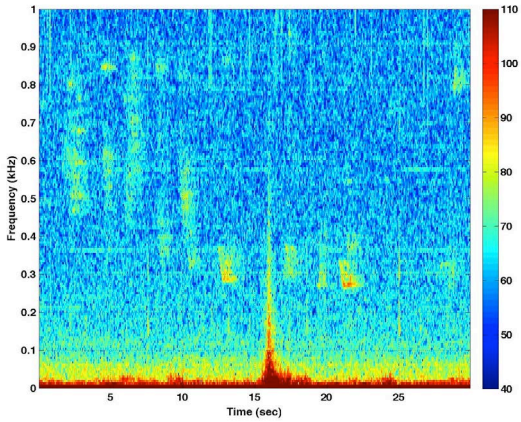

Figure 3: Humpback whale calls detected on 10 m aperture vertical array at 287 m depth on 6 Aug 2010, 04:55:41.

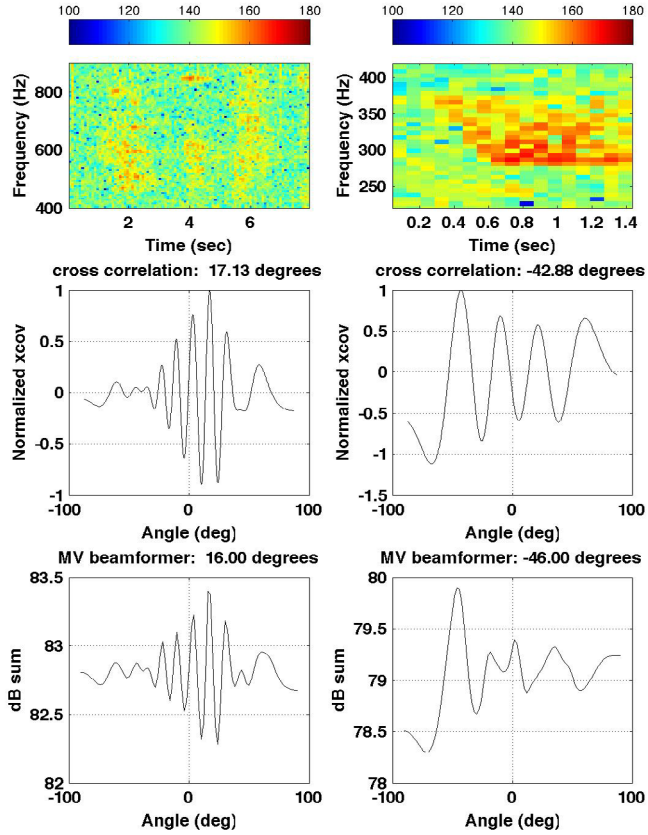

Figure 4: Vertical elevation angles measured from humpback whale calls. Left column: first three calls in Fig. 3. Right column: 250-400 Hz visible at 22 s in Fig. 3. First row: spectrogram. Second row: elevation angle determined by cross-correlation between two hydrophones 10 m apart. Bottom row: elevation angle determined by minimum-variance beamforming (MB) the signal. Positive elevation angles are rays arriving from the ocean floor, negative angles are arriving from the surface.

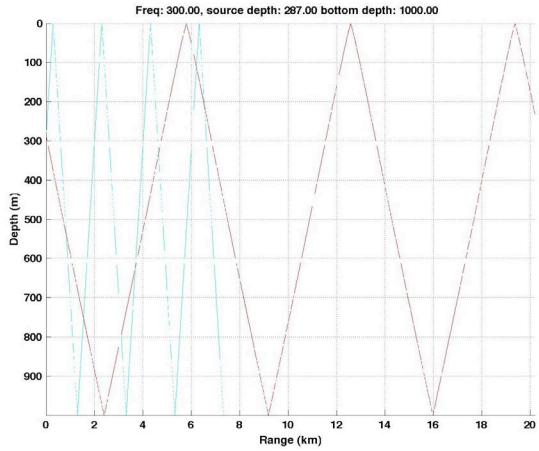

Figure 5: Ray tracing of calls in Fig. 4. The red path corresponds to the bottom-reflected calls shown on the left column of Fig.4, while the cyan path corresponds to the right column. The results illustrate the range ambiguities inherent in bottom-reflected paths, when no information is available besides elevation angle and estimated calling depth.